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NEAR MISS WARHEAD TECHNOLOGY WITH MULTIPLE EFFECTS AGAINST SUBMUNITION PAYLOADS

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Abstract

Direct hit missile technology over the last 15 years has significantly reduced miss distance distributions against ballistic missile payloads. With this significant decrease in miss distance, future warhead technologies do not need to extend out to large miss distances to kill targets. These new concepts are only required to expand with high spray density clouds of deployed mass. A new class of warhead technologies coined "near miss warheads" has been analyzed at Raytheon to investigate near miss warhead lethality against payloads carrying submunitions. These warheads utilize most of their entire mass as penetrators generating near 10 to 30 times more mass deployed in the target's direction when compared to today's warheads. This report also discusses in detail multiple impact effects from these special classes of warheads. These tightly spaced projectiles combined with temporal spacing create a synergetic or flood loading effect, which generates high overall lethality against submunition payloads. These new warhead technologies are gaining more attention because TBMs of tomorrow could contain countermeasures, which would create small misses leaving no lethality.

Direct Hit Consideration

Sled track testing combined with 1/4-scale light gas gun testing has demonstrated the damage potential of direct hit missiles. These missiles utilize the target's velocity to generate extremely high relative velocities to kill chemical submunition payloads. Currently, flight-testing as successfully demonstrated these missile concepts can achieve direct hits on enemy TBM missiles. These tests demonstrated direct hits on a TBM payload under well-behaved engagement conditions with favorable kinematic parameters. It is still unclear how well the direct missile hit missile would perform when non-optimum engagement conditions occur. A figure showing a direct hit impact from a flight test and a sled track damage test are shown in Figure 1.

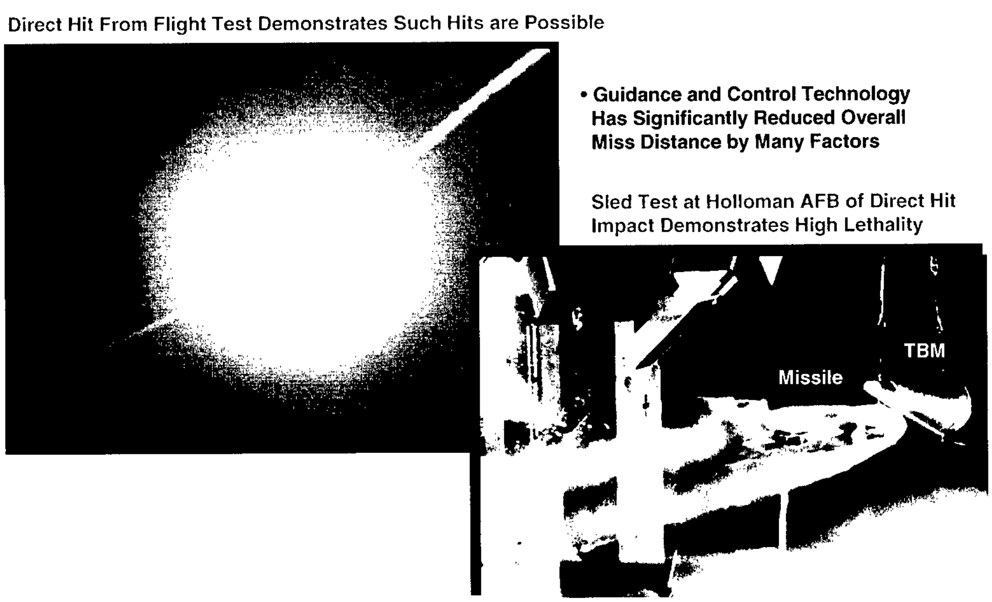


Figure 1. Direct Hit Technology Highly Lethal when Optimum Aimpoint is Hit

The sled track and 1/4-scale tests clearly demonstrate that direct hit missiles must impact near the optimum aimpoint to achieve high lethality. Dr. Hans Mark said it best "direct hit is like bowling, if you do not hit the exact point then many will continue to stand." This analogy is very true and has been proven through sled and scaled testing with analysis. Another problem with direct hit only systems is it contains a large lethality gradient around the optimum hit point. These small contours are very close and the difference between high and low percent killed could be small axial miss. To compound this and make matters worse, if the relative velocity is low then even if the optimum impact point is hit there could still be surviving submunitions. Generic lethality performance trades of direct hit only versus direct hit with a kinetic energy rod warhead is shown in Figure 2.

Another major reason why anti-ballistic missiles need to incorporate near miss warhead technology is tomorrow's ballistic missiles may contain countermeasures. These countermeasures appear easy to implement and may easily distract our direct hit missiles to miss the payload. Remember, if our direct hit missile misses the payload by its missile radius (co-plainar) then it would completely miss the target. These countermeasures could also cause slight inaccurate aim point shifts reducing the overall missile system lethality to zero. One simple countermeasure that would significantly reduce direct hit lethality is shifting or modifying the payload to a new location. This slight shift would counter our knowledge of where we thought the payload location is. This new location would be undetected and the missile would fly through where old data had suggested it should be. Another technique that would detour direct hit missiles is commanding the TBM to maneuver in a random manner to evade an incoming missile. The last countermeasure, which was seen in the Gulf war but not intended, is breaking up. As the missile passes into the atmosphere it breaks up into many large and small pieces. The missile must discriminate between all the debris and determine which object is the warhead. Once it has found the warhead then direct hit processes are initiated.

All these countermeasure concepts are potential error sources that direct hit missile designers must take into account. If these maneuvers are not countered then today's missiles will miss allowing all the payload to perform its intended mission. This is another strong argument why near miss warhead technology is critical and must be considered in tomorrow's defense systems. An illustration of some potential countermeasures is shown in Figure 3.

Near Miss Warhead Technology

Today's blast fragmentation warhead technology is not capable of perforating many chemical submunitions on a payload. These warhead designs use less than half of the total warhead weight as penetrating fragments. This warhead only uses 5 to 10 percent of its total metal weight to kill the target. This lack or waste of mass is the major reason why these warheads perform so poorly against submunition payloads. This is shown in Figure 4.

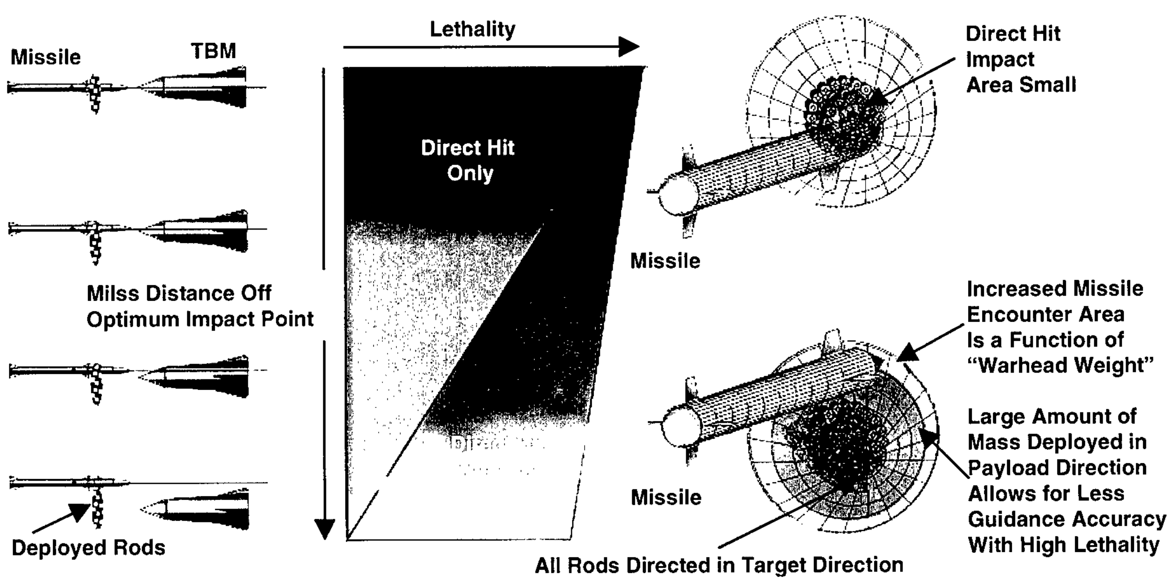


Figure 2. Direct Hit Missile Lethality Extremely Sensitive to Impact Point

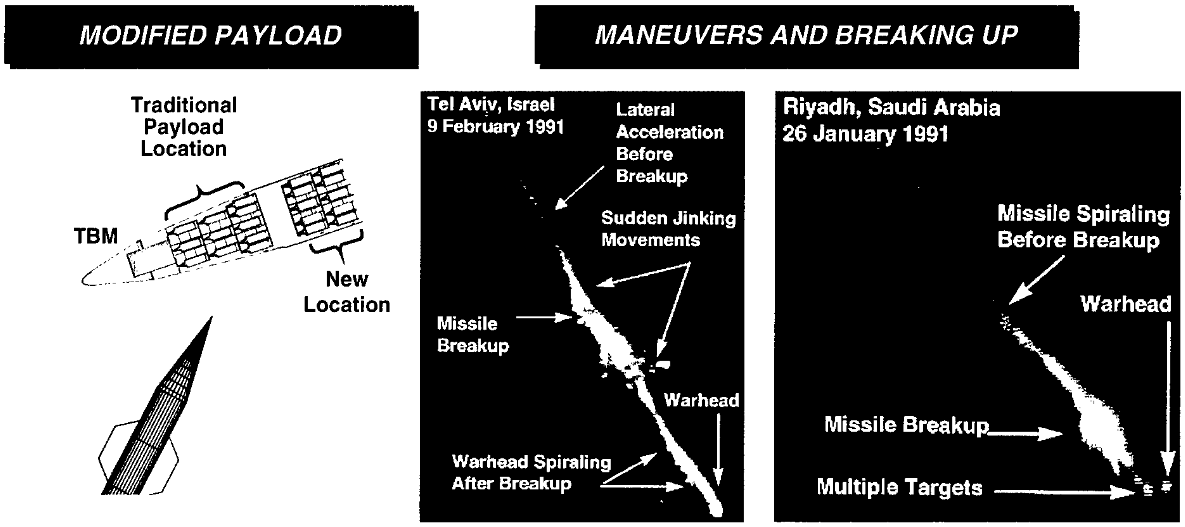


Figure 3. Direct Hit Technology must Account for Countermeasures

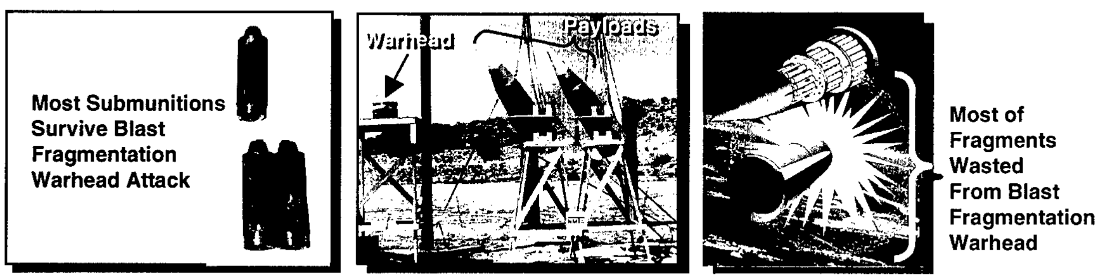


Figure 4. Future Warheads do not Need to Reach Out and Kill TBM Payloads at Large Miss Distances

Today's blast fragmentation warheads are designed with explosive charge (C) to mass (M) ratios (C/M) near 1.0. This is desired in order to obtain high fragment velocities near the missile and target's closing velocity. The benefit achieved from these high velocities is lower impact obliquity angles which allows deep fragment penetration.

Near miss warhead technology combines direct hit missile accuracy with mass focussing warhead effects. This technology enhances the total metal deployed in the target's direction using near all of the total warhead weight as penetrators. These warheads are more efficient compared to traditional warhead technologies making them highly lethal and desirable. An illustration of a near miss showing a directional cloud of rods deployed in the target's direction is shown in Figure 5.

Raytheon has investigated new warhead technologies that can obtain high lethality against submunition payloads. These new warhead concepts contain small amounts of high explosive with most of its overall weight being high-density penetrators. These new warhead concepts contain a low C/M ratio with very dense spray patterns deployed in the target's direction. These new warheads generate highly dense spray patterns, which flood load or impulse a target with many closely spaced impacts. These closely spaced impacts enhance the overall lethality against thick walled submunition payloads. It has been demonstrated that this new classes of warheads are highly lethal when combined with direct hit missiles.

Aimable Kinetic Energy Rod Warhead

Kinetic Energy (KE) rod warheads are designed with 70 to 80 percent of the charge (C) plus mass (M) weight as metal penetrators. Since the KE-rod warhead is designed with small C/M ratios, they deploy all of their rods in the target direction. The idea is to launch a curtain of rods at low ejection velocities and let the missile and target-closing velocities supply the total kinetic energy. This warhead design concept relaxes the fuzing requirement and allows large range errors. Typically, ejection angles vary between 25 and 75 deg and are achieved by selecting and detonating explosive

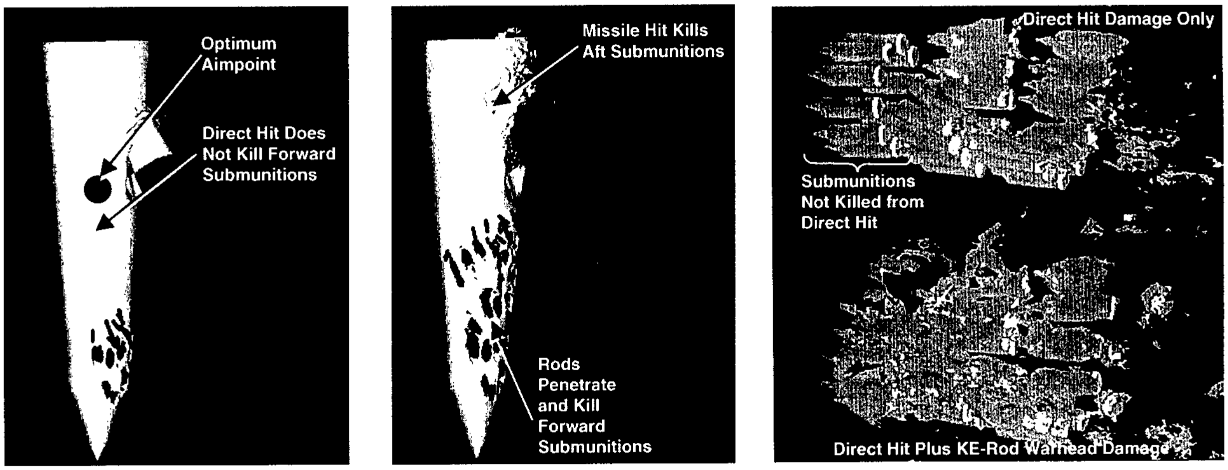


Figure 5. Future Warheads Technologies Benefit from Small Misses and Designed to Deploy 10 to 30 Times More Mass on the Target

segments. These segments correspond to a desired ejection angle that will obtain maximum lethality. If the miss-distance is large, then a tight high-density beam of rods is deployed. However, if a small miss-distance is achieved, then a pattern or rods is deployed which spreads open quickly in order to cover the entire payload. An illustration of two different types of aimable rod warheads is shown in Figure 6.

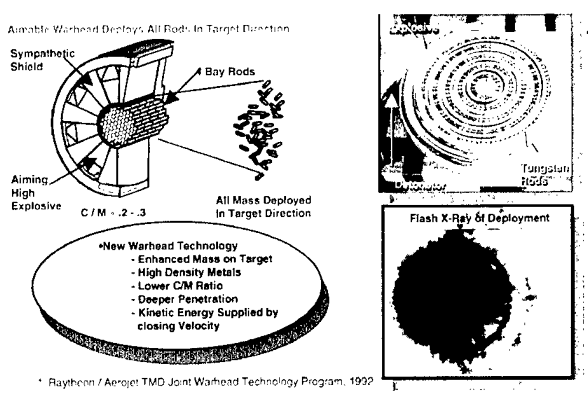


Figure 6. Aimable Kinetic Energy Rod Technology is Fully Directional Deploying All Penetrators in the Target's Direction

The warhead is shown deploying all four bays of rods in the target's direction. A sympathetic shield is used between neighboring explosive segments to ensure detonation does not occur prematurely. An aimable jellyroll warhead with a flash X-ray is shown on the right. This warhead was tested by Aerojet during a Raytheon/Aerojet joint TMD program in 1992. The test warhead contained 272 tungsten rods with detasheet explosive on the end. This warhead also contained detasheet between each layer of rods. This explosive is used if the warhead is detonated using its isotropic mode.

Isotropic Rod Warheads

An isotropic rod warhead is used when the direct hit missile achieves a direct hit. This mode is used to slightly enhance the missile's impacting diameter. The idea is to use the aimable potion of the warhead when the missile misses the target. However, the rods are isotropically deployed when a direct hit occurs. This detasheet explosive is inserted between each foam buffer. The tungsten rods are packaged on top of the thin foam buffer, which prevents fracture or breaking during deployment. The rods are deployed slowly prior to impact making the missile slightly larger. Those deployed rods kill submunitions that may fall outside the direct hit damage volume. These warheads are shown in Figure 7.

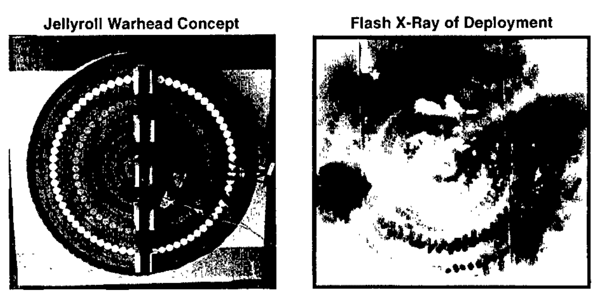


Figure 7. Isotropic Warhead Concepts Increase the Missile Diameter by Deploying a Slowly Expanding Disk of Projectiles

Jettison Warhead Technology

Aerojet built and tested this warhead concept during the joint Raytheon TMD technology program. These warheads contain small thrusters fueled by propellant chambers. The rods are packaged on the warhead in consecutive layers. The warhead is thrusted to the predicted miss distance where the rods are then slowly deployed. These projectiles create a high-density cloud in front of the incoming ballistic missile. These warhead concepts are shown in Figure 8.

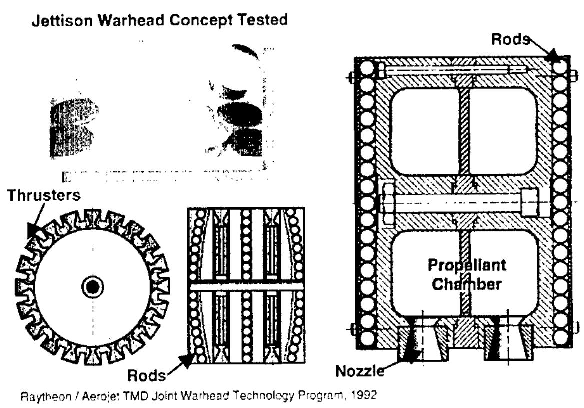


Figure 8. Jettison Warhead Technology Deploys Entire Warhead in Path of Ballistic Missile

Isotropic and Aimable Modes

The KE-rod warhead concept is designed with two modes of deployment. When the missile achieves a direct hit these rods are deployed about the missile axis. A ring of rods is deployed about the missile killing submunitions that are not killed from the direct hit impact. The isotropic mode does not have to contain a jellyroll explosive ring. Several other isotropic techniques are designed by exchanging the PETN spiral with foam. The form adds a buffer creating a different impedance miss match between the materials.

This difference in impedance helps separate the rods after deployment. The central explosive core is the primary mechanism that is used to deploy the rods. The spiral can also be taken out just leaving a central core to deploy the rods. This deployment pattern takes the shape of a toroid pattern. In order to fill the hole in the middle of the spray pattern the explosive in each bay is stepped. This explosive stepping creates a different C/M ratio per bay giving different rings of deployed rods. These different ring diameters fill in voids creating a uniform spray pattern.

If a miss occurs then the directional explosive segments are initiated. These explosive segments deploy all the rods in the target's direction killing many submunitions. The size of the directional pattern is controlled by the number of initiators fired and the resolution that they are assembled on the warhead. This directional mode allows near miss warhead technology to obtain high lethality against submunitions at large miss distances. The mode of operation for both isotropic and aimable concepts is shown in Figure 9.

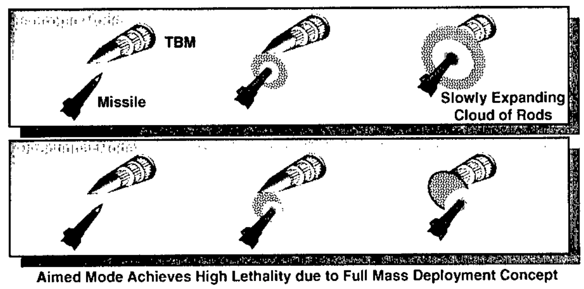


Figure 9. Isotropic and Directional Rod Warhead Modes of Operation

Jettison Mode of Operation

The propellant chamber on a jettison warhead is used to accelerate the entire warhead to the predicted miss distance. A this time the fragment layers are slowly deployed creating a series of waves that attack the payload. The idea is to let the first wave impact and initiate damage. The second wave is timed to impact after the debris from the first wave has cleared. The third wave is also timed to impact after the second wave of debris has cleared away from the payload. The overall idea is to let the warhead strip away the target by using propellant to accelerate the warhead to the proper point in front of the target. An illustration of the jettison warhead concept mode of operation is shown in Figure 10.

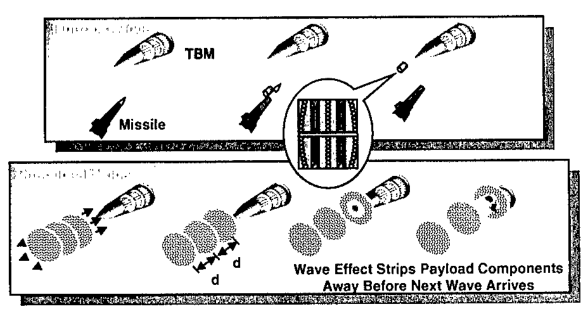


Figure 10. Jettison Multiwave Warhead Mode of Operation

Kill Mechanism Concepts

Hydrocode and endgame models can be used to investigate different kill mechanisms that would achieve high levels of kill against submunition payloads. A popular question that is often asked when designing kill mechanisms to kill submunition payloads is "should the projectile be a cube or a rod and should it be a small or large projectile?" The idea is there are many small lightweight projectiles compared to fewer massive ones and cubes are insensitive to yaw while rods are. Before these questions are addressed one must first investigate each target submunition payload separately. The idea is to generate many shotlines through the target and gather all pertinent penetration statistics along the shotline. These shotlines give valuable information on the number of submunitions that exist on a given ray. The percent of submunitions seen as a function of visible submunitions is plotted as a function of strike angle. If a second submunition does not appear often along any shotline, then designing a rod with enough mass to penetrate one and go into another is wasteful. If this occurs, small rods or cubes would be the best choice because the probability of a second perforation is small. However, if there is a good probability that a second submunition does exist along a shotline then a rod could be designed large enough to penetrate the first one with sufficient mass to penetrate a second one. Obviously, these statistics vary depending on the strike angle and total number of submunitions. a RAYSCAN shotline map against a representative submunition payload is shown in Figure 11.

The total number of submunitions that exist along a shotline is directly related to the number and the packing density of the submunition. Obviously, a payload that contains many submunitions contain a higher probability of seeing a second and third submunition along its shotline.

Unique and novel kill mechanisms are currently being investigated at Raytheon to enhance the overall damage to submunition payloads. The use of non-circular cross-sections may prove to enhance the total damage to ballistic missile payloads. From a KE-rod warhead design prospective there is a limited volume that the warhead occupies on the missile. The total rod penetration and number of penetrators on the warhead are obvious key parameters that influence the warhead lethality. A comparison can be made between a traditional cylindrical rod to novel rod cross-sections. An illustration of several novel penetrators with hydrocode calculations is shown in Figure 12.

A rod concept was evaluated that contained anti-neutralization material inserted inside a hollow rod. The rod is designed with holes and a plunger weight. When the rod impacts a target, the flunger weight is accelerated through the rod compressing the material through the holes. This material mixes with the payload agent and provides some level of neutralization. An illustration of the concept with a SPHINX hydrocode calculation of penetration and material deployment is shown in Figure 13.

Endgame Simulation Overview

A new 3-dimentional endgame simulation named RAYSCAN has been developed to model the damage from multiple impacts against ballistic missiles. This simulation is a new Raytheon version of SCAN which was originally develop by the Navy at the Pacific Missile Test Center at Point Mugu, CA. RAYSCAN was modified to design and assess warheads against Ballistic Missiles. The code has been upgraded to address lethality of near miss warhead technology. Below is a list of several major features of the simulation.

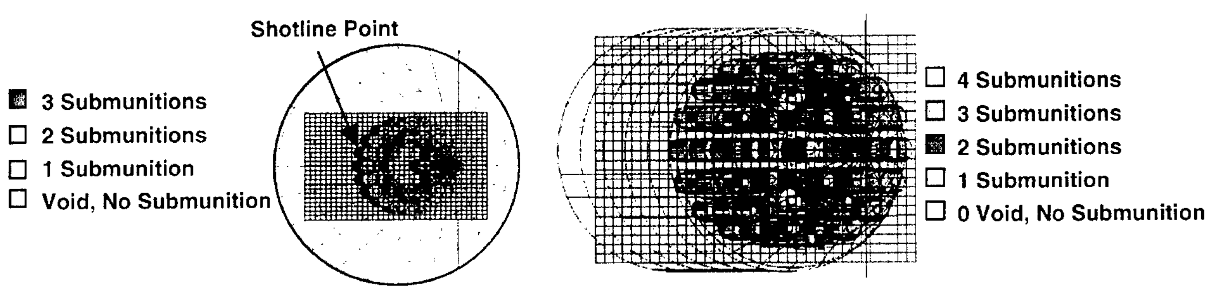


Figure 11. Penetration Shotline Statistics to Determine Visible Submunitions

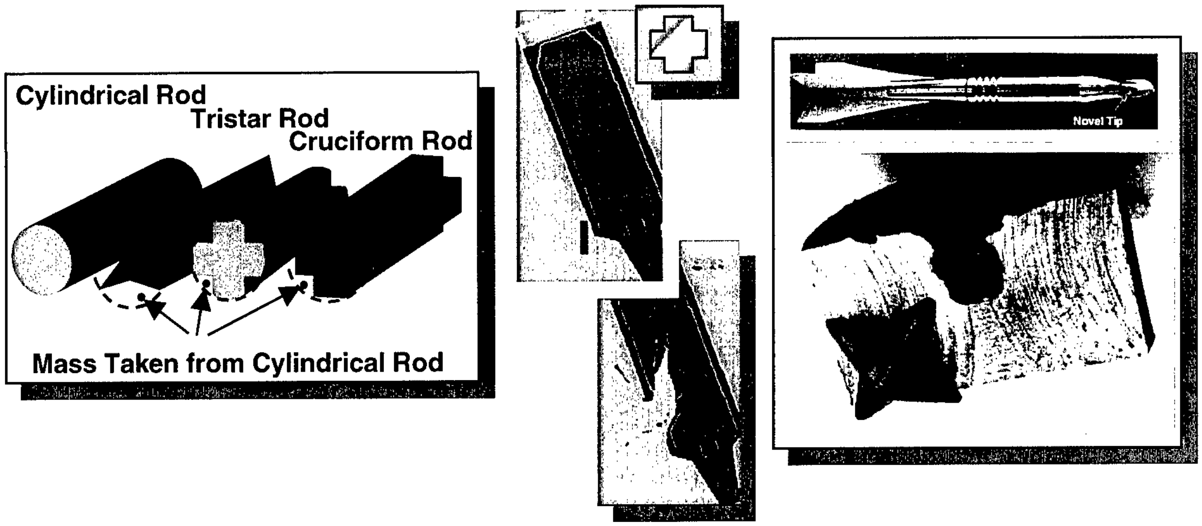


Figure 12. Novel Penetrator Concepts with Hydrocode Calculations

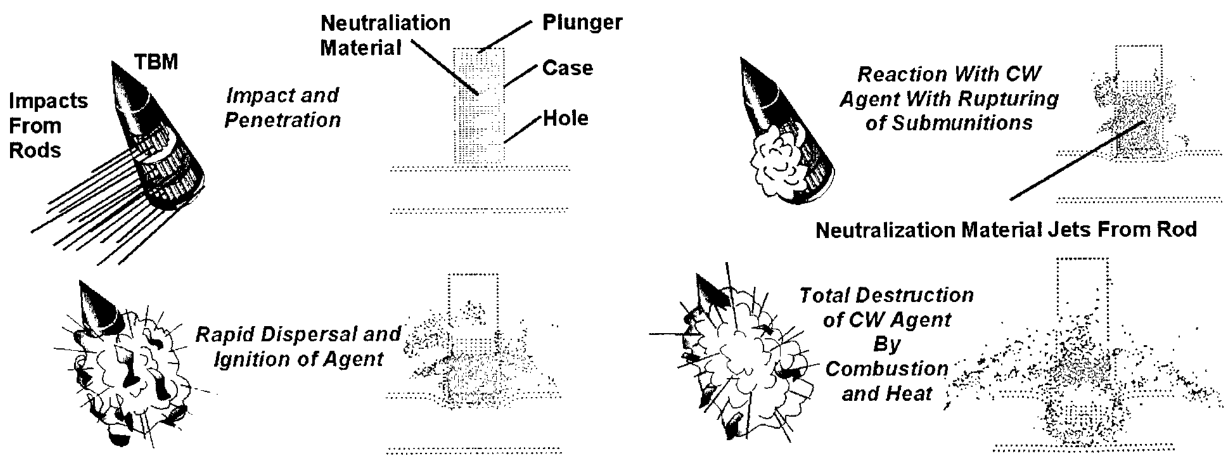


Figure 13. Anti-Neutralization Kill Mechanisms Concept

- New multiple impact logic
- Detailed warhead description
- Penetration equations (FATEPEN, TATE, KARPPEN)
- Detailed target model with 12 material selections
  - Total Energy, normal energy, area removal, explosive initiation (Jacobs-Rousland), $P_K = C_1 + C_2M + C_3V : C_1, C_2, C_3 =$ Constants, Table Lookup (Velocity/Mass/Obliquity), COVART Data
- Parametric Trajectory or 6DOF Interface
- TDD or GIF Fuzing
- Blast Effects
- Graphical Display

A designer has the versatility to generate target models using actual component materials. These target materials are contained and predicted in the penetration equations. The FATEPEN penetration equations are incorporated in the endgame code where spheres, rods or parallelepipeds are potential projectile shapes. These equations compute tungsten fragment and rod penetration. A new tungsten rod penetration model was developed at Raytheon, which is based on yawed rod penetration equations.

Multiple Impact Modeling Overview

New modeling techniques are required to accurately model near miss warhead technology. These warheads generate a highly dense pattern of fragments on the payload taking advantage of the closely spaced distances between impacts.

Endgame simulations are widely used to assess the damage from kinetic energy penetrators. The damage inflicted to the target is strongly a function of impact velocity, mass, density and obliquity angle. Vulnerability data is generated for all pertinent internal components while specific kill criteria and fragment residual energies determines if the component is killed. Endgame codes do provide some level of weapon lethality or figure of merit when comparing warhead concepts. These codes raytrace each projectile one at a time through the target not taking into account damage from closely spaced neighboring projectiles. Warheads that generate fragment spacing that is somewhat sparse generate accurate fragment lethality along a given shotline. These sparse impacts allow each fragment to inflict target damage only from itself. However, in close warheads generate highly dense clouds of projectiles that are spaced very close to each other. These deployed clouds contain length with tight spacing of all the projectiles. Current endgame codes model rod penetration one rod at a time. This repetitious type of single impact analysis isolates each rod as an isolated event. These types of weapons require new endgame logic to model the enhanced damage from sequential and temporal spaced impacts. The difference in sparse versus not sparse impact patterns is shown in Figure 14.

These combined interactions are currently modeled with a hydrocode taking full credit of multiple impacts with close spacing. However, these large runs are challenging and require many particles or cells to predict damage accurately. An example of a run with SPHINX is show in Figure 15.

The cumulative damage is computed by the hydrocode but total computation times take up to 24 hours using a mini-super computer with 400,000 particles. New endgame penetration damage methodologies need to be developed in order for an endgame code to model sequential impacts. Warhead design trades are performed parametrically and require fast running engineering codes to perform thousands of runs. Hydrocodes currently take many hours to produce one trade concept. However, in time new and faster computers may make these codes the ones of choice. For now, endgame codes must model multiple impact damage and new multiple impact methodologies are required.

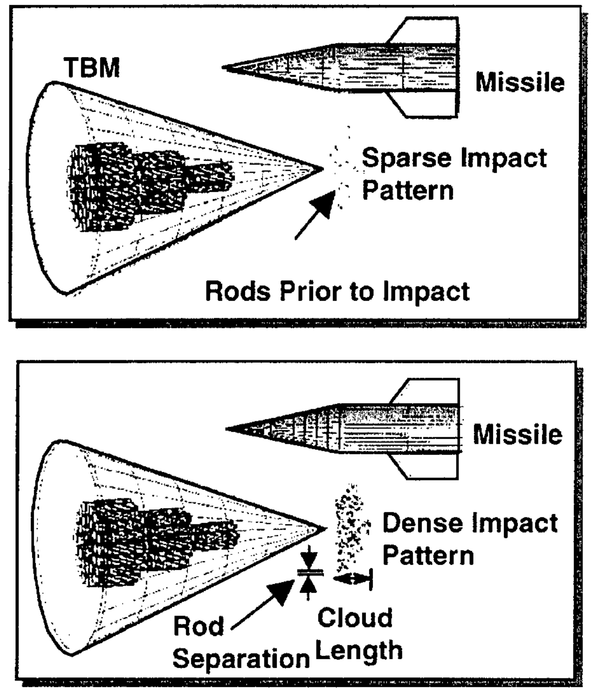
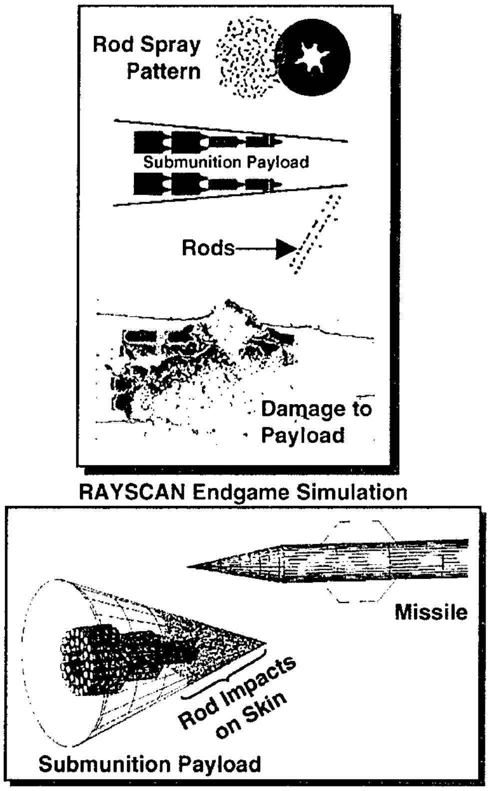


Figure 14. Endgame Comparison of Sparse and a Highly Denser Pattern

The initial steps were taken to investigate and model multiple impact effects created from near miss warheads. High-density material impacting very close together generate enhanced damage on target components. This enhanced damage from multiple penetrators needs to be modeled with today's endgame codes.

Multiple Impact Modeling Against Ballistic Missiles

The RAYSCAN endgame simulation has a new damage prediction technique to predict multiple impact effect from highly dense clouds of projectiles. These new models have been applied to predict damage against ballistic missile payloads. This new model attempts to predict more accurately the damage from near miss warhead technology. The TBM skin, payload type and submunition types have been separated into different damage models to address the variations in failure mechanisms. A different damage methodology has been developed for the TBM skin compared to the other components on the target. The skin usually consists of thin metal combined with composites. After the warhead projectiles penetrate through the TBM skin



Run Time: 30 Seconds

Figure 15. SPHINX Hydrocode Run Demonstrating Cumulative Damage Compared to Existing Endgame Code

they continue on and strike the payload. If the payload is integral to the TBM skin then the shroud containing the warhead is actually part of the target skin. The shock waves and spall debris from the skin react differently over the payload when compared to an integral warhead. Since the payload shroud is not in direct contact with the outer skin it is impacted with primary and secondary fragments. These bulk payloads configurations usually consist of chemical, high explosive or nuclear warheads. High density multiple impacting fragments will damage differently each payload type causing different types of damage. The most stressing payload to kill is the chemical submunition payload configuration. This warhead contains many submunitions, which are internal relative to the outer TBM skin. A photo of multiple impact testing that was conducted against a TBM skin, bulk tank and submunition payload is shown in Figure 16.

Penetration Model Development

The multiple impact mode developed for RAYSCAN is based on the penetration of a single projectile through a target plate. The RAYSCAN simulation currently uses three different kinds of penetration models to compute overall damage. These models are FATEPEN, TATE and a new yawed rod penetration routine based on Wollman yawed rod and fragment data (KARPPEN). The main formula to compute penetration is

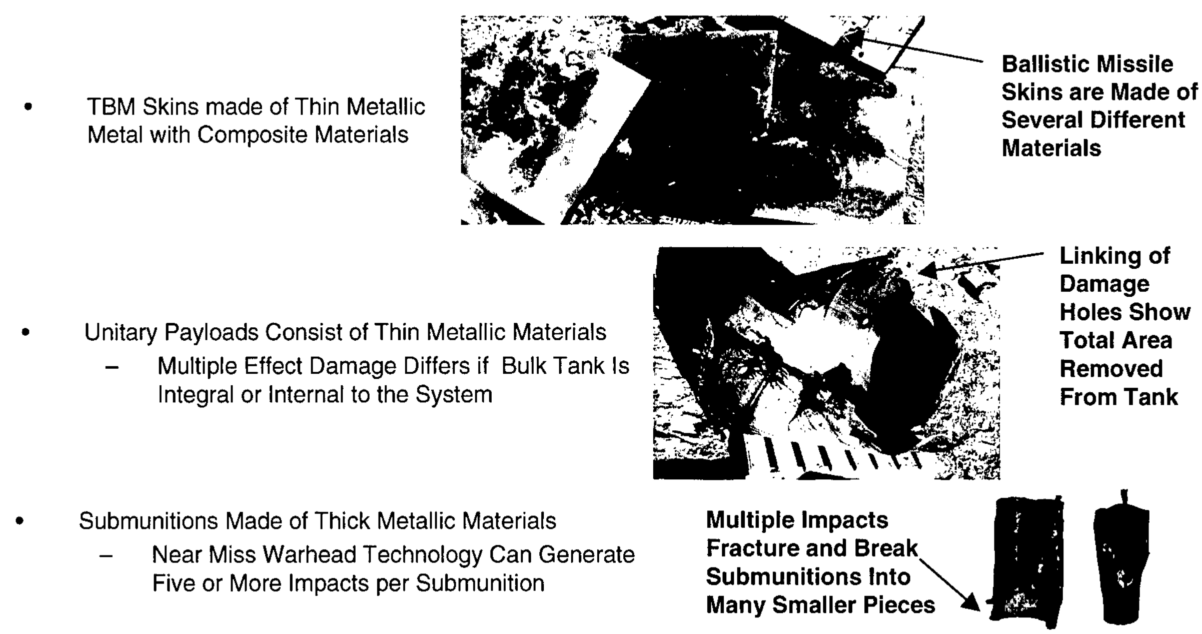


Figure 16. Multiple Impact Model Currently Under Development to Predict Better Multiple Impacts Damage against Skin, Unitary and Submunition Payloads

$$\left(\frac{P}{L}\right)=\left(1.0-\frac{D}{L}\right)\mu\left(1.0-e^{-V/0.6}\right)^{8}+2.64\frac{D}{L}\left(\frac{V}{4}\right)^{2/3} \qquad (1)$$

where $P_0 = L\,(P/L)$ and $P_l = D\,(P/L)$. The total penetration is P while the rod length is L. The rod impact velocity is V while $\mu = \sqrt{\rho_P/\rho_T}$ where the initial rod diameter is D. If D/L equals 1.0, then the left side of the equation equals zero. The penetration equation for a cube is now equal to the right side. The initial penetration equation is for normal impacts only while yawed penetration methodologies are introduced by

$$P=\left(P_0-P_l\right)e^{-\alpha\left(\beta/\beta_{crit}\right)^2}+P_l \qquad (2)$$

where $\alpha = 0.2\,(L/D)^{-0.8}$. The critical yaw angle $\beta_{crit} = \sin^{-1}$ (H/D - 1.0/2 (L/D)) where β is the actual yaw angle at impact. The crater diameter is computed by equating the work done to move the target element a distance dr. The rate of work is

$$\dot{d}W = Fdr = R_T urdrd\theta \qquad (3)$$

where the work performs over the entire circumference and radius is

$$\dot{W}=\int_{r_R}^{r_C}\int_0^{2\pi} R_T \underbrace{urdrd\theta}_{\text{plate wall element}} = R_T u 2\pi\frac{r^2}{2} = \pi\left(r_C^2-r_P\right)R_T u \qquad (4)$$

The projectile radius is rP and the crater radius is rC. The strength of the target material is RT. The above equation can now be expressed as a function of the crater area and projectile area. The equation now becomes

$$\dot{KE}=\frac{1}{2}\dot{m}v^2=\dot{W}=\left(A_C-A_P\right)R_T u = \frac{1}{2}\rho_P A_P\left(v-u\right)\gamma^2 \qquad (5)$$

where the rate loss of kinetic energy is $\dot{KE}$. The balanced equation can now be solved for crater diameter. The crater diameter is

$$\left(\frac{d_c}{D}\right)^2 \cong 1+\frac{1}{2}\rho_P\frac{(V-u)}{R_T}V\,(1+\mu) \qquad (6)$$

The penetration rate u is

$$u=\left[V-\mu\left(V^2+A\right)^{1/2}\Big/\left(1-\mu^2\right)\right] \qquad (7)$$

where

$$A = 2\left(R_T-Y_P\right)\left(1-\mu^2\right)\big/\rho_T \qquad (8)$$

An illustration of several single test shots into thin plates is shown in Figure 17.

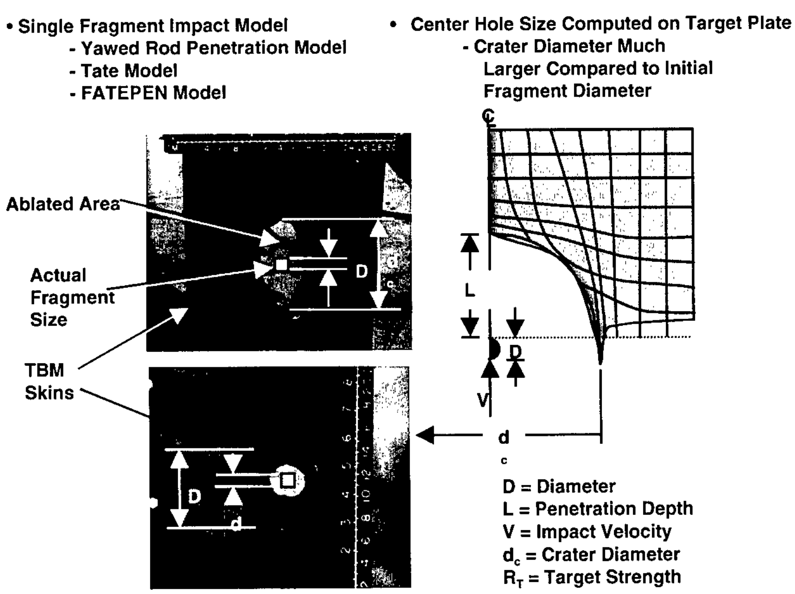


Figure 17. Multiple Impact Model Based on Single Penetration Equations

The skin on the TBM is currently modeled as many small elements. The element size selected is somewhat a function of projectile diameter, but smaller elements give better overall damage resolution. However, more elements do require increased computing by the simulation with increased run times. The principal stresses on each side of the element is computed based on hole size and stress constitution factor methodologies. If the tensile stress of the impacted element is less then the fragment induced principle stress, then the neighboring element is considered damaged and taken out of the calculation. The penetrated element is surrounded by eight neighboring elements and after impact they are all flagged as potentially damaged. In order for a neighboring element to be fully damaged the principle stress must be greater than its ultimate tensile stress over half the element length. If it is not, then the element is not considered fully damaged and is left in the calculation. The RAYSCAN simulation analyzed a target plate with a 1 x 1 in. and 3 x 3 in. grid. The RAYSCAN simulation damage is compared to a test plate as shown in Figure 18.

The results appear to be more accurate with the smaller grid size. This smaller element resolution gives better incremental damage predictions of each plate element. The entire hole diameter is calculated first from the previous equations. After this calculation is performed the entire set of elements are disseminated and deleted. After this is performed the stress distribution is compared to all neighboring elements. The determination of the stress distribution in a plate with a circular hole is computed by σ_r, σ_θ and $\gamma_{r\theta}$ equation.

The radial and axial stress components are converted to principle stresses and compared to the tensile stress (σ_T) of the element.

Testing of higher spray density patterns were performed against representative skin plates where extensive linking occurred. The test demonstrated most of the target skin is removed from the entire plate. The RAYSCAN linking mode demonstrated similar visual damage levels as seen in testing. The multiple impact damage model also accounts for projectiles that ricochet or do no penetrate the target element. A projectile could strike the target and only penetrate some small distance and stop. The model will compute the total penetration and compare it to the element thickness. These distances are subtracted and the element is reassigned a new thickness. This new element may be impacted by a neighboring projectile with some temporal spacing. The second projectile takes advantage of the first projectile damage and proceeds to penetrate easier through the target plate. An illustration of the RAYSCAN prediction with test damage is shown in Figure 19.

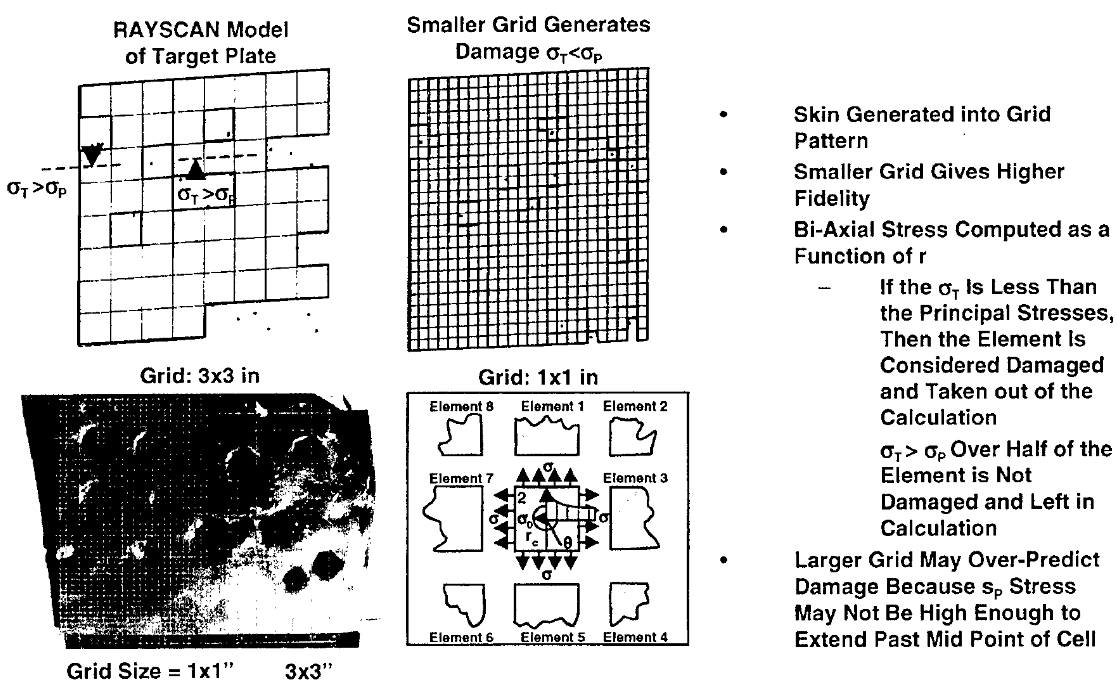


Figure 18. Multiple Impact Model in RAYSCAN Compared to Test Plate

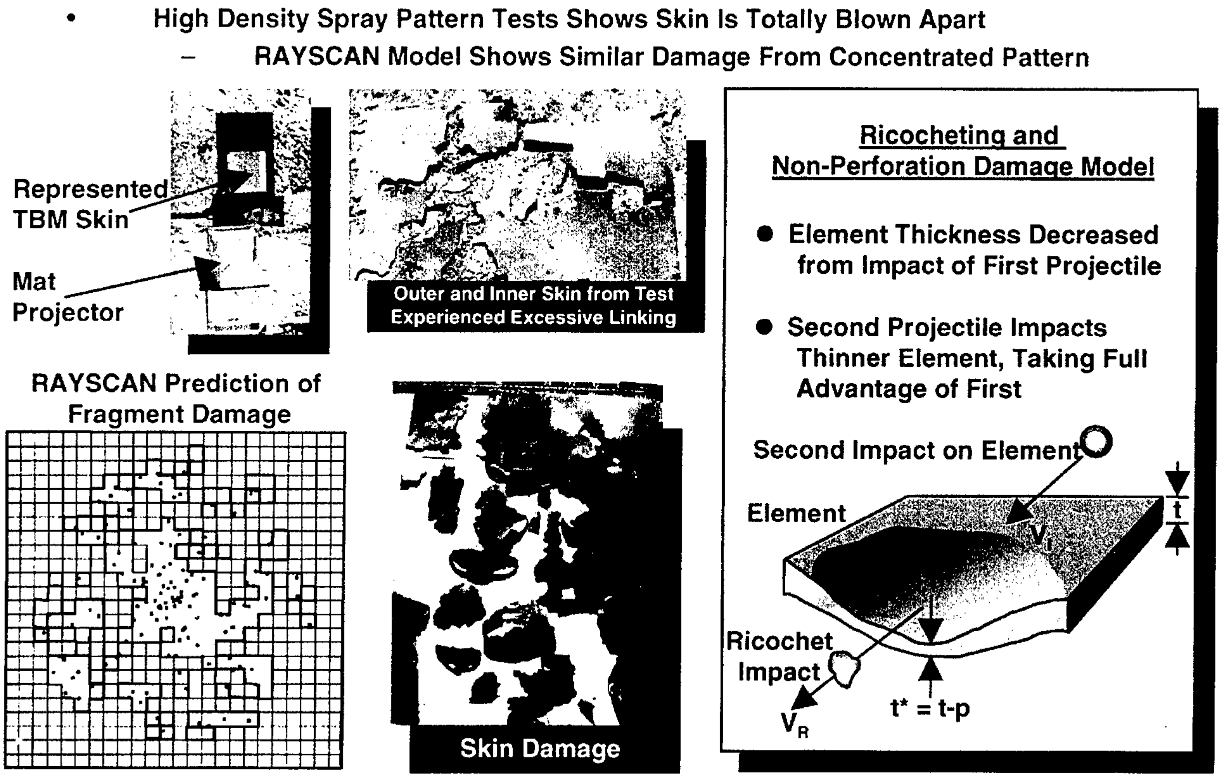


Figure 19. Stress Loads on Each Element Demonstrating Linking Model Supplement

Bulk and Submunition Warhead Calculation

The damage model has been configured to model the damage to bulk payload skins and submunition payloads. The same logic used on the skin model has been incorporated to those structures. A bulk tank was built in RAYSCAN and compared to several Mat-projector tests. A high-density array of fragments was fired through a representative TBM skin and then into a water filled bulk tank. The high-energy fragment pattern completely opened the entire tank. The RAYSCAN model also fired various numbers of projectiles and showed similar damage levels as seen in testing. Those damage levels of both the test and simulation are shown in Figure 20.

Hydrocode analysis combined with testing determined the representative element size to be used against submunition payloads. The element size was selected based on fragment hole sizes that were seen from single fragment impact tests. This is shown in Figure 21.

The same logic that was developed for the skin was modified to accommodate the unique nature of the submunition payload. An illustration of a RAYSCAN generated pack of three submunitions with single fragment testing is shown in Figure 22.

The same test was conducted but in this case a second fragment was fired with a small time delay relative to the first fragment. The test demonstrated that the combined damage from both projectiles could penetrate into the second submunition. The RAYSCAN model was employed and the same results were calculated. The RAYSCAN model predicted accurately the damage from multiple impacts. This damage calculation is shown in Figure 23.

Penetration Versus Fragment Spacing

There is a difference between temporal spacing and closely spaced multiple impacts. The temporal spacing model computes the penetration and damage from the first impact only. The simulation continues on and determines which elements are deleted from the calculation. Now, the second impact can take full advantage from the deleted elements. The second fragment now can penetrate deeper into the target payload.

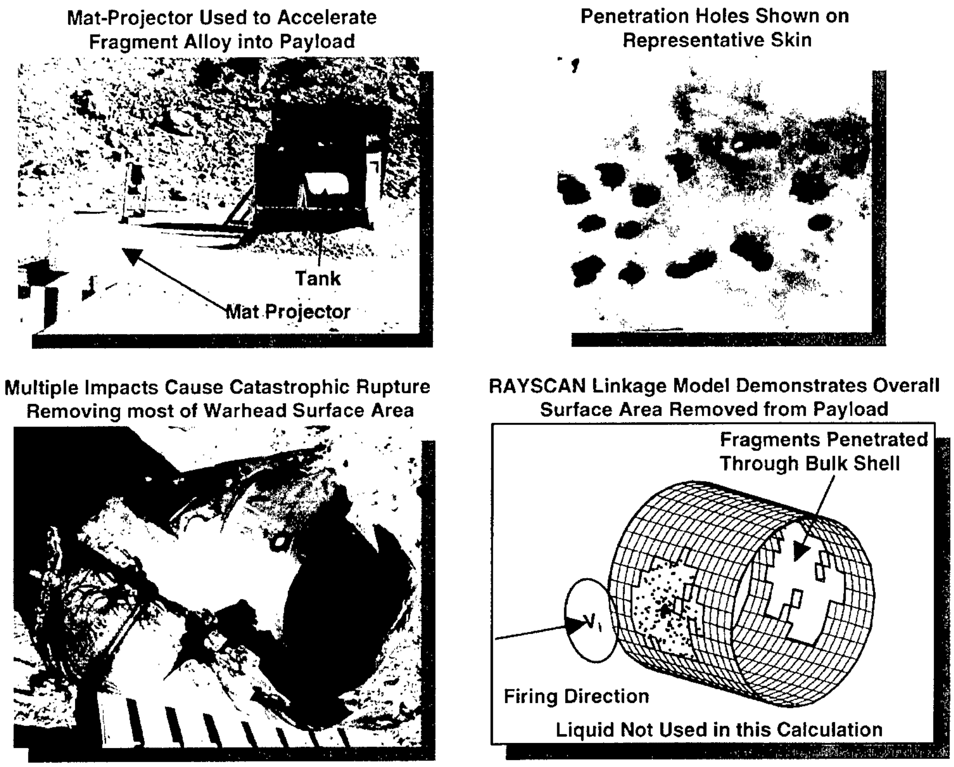


Figure 20. RAYSCAN Multiple Impacts against Submunition Payload

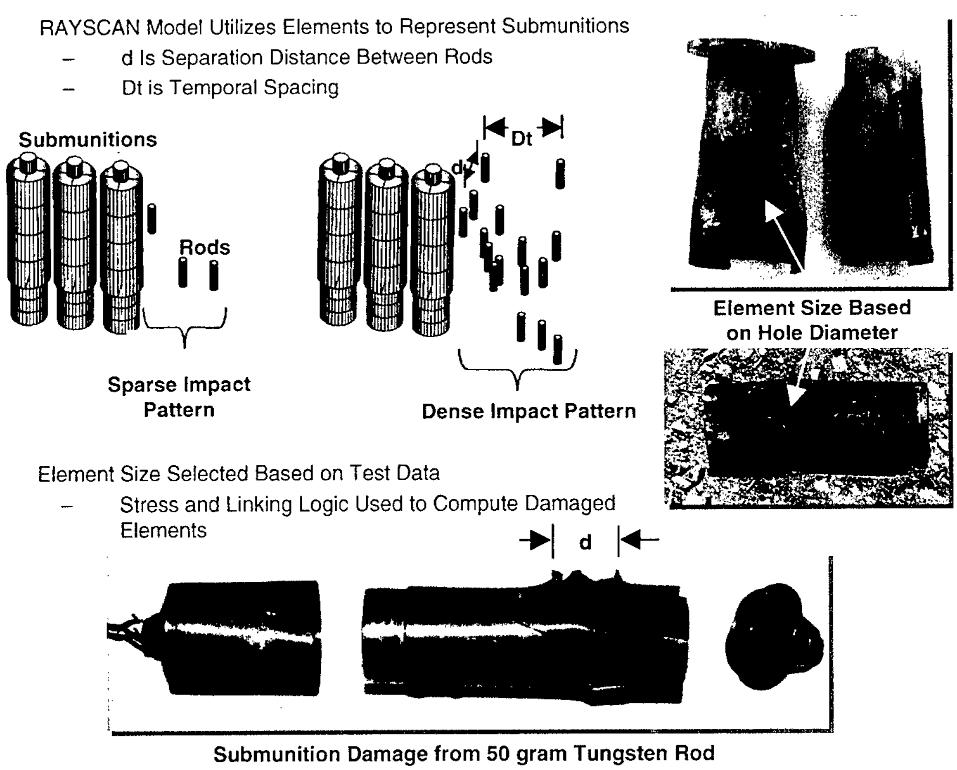


Figure 21. RAYSCAN Damage Model Incorporated into Bulk Payload Configuration

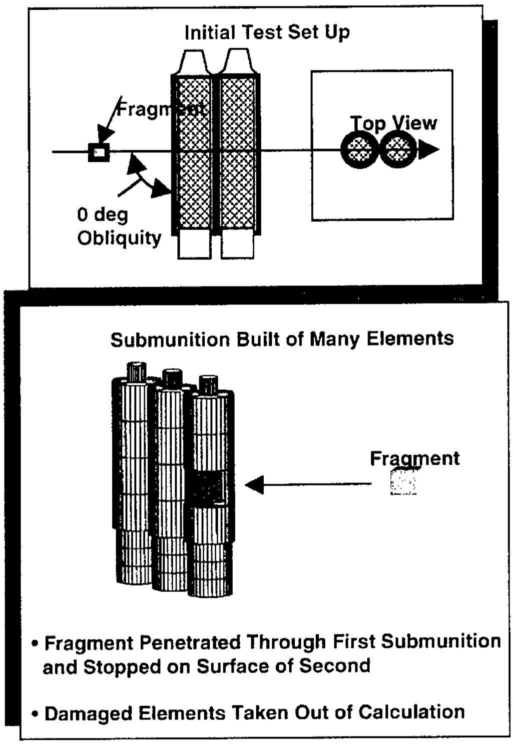


Figure 22. Enhanced Damage Calculated from Multiple Impact with Temporal Spacing

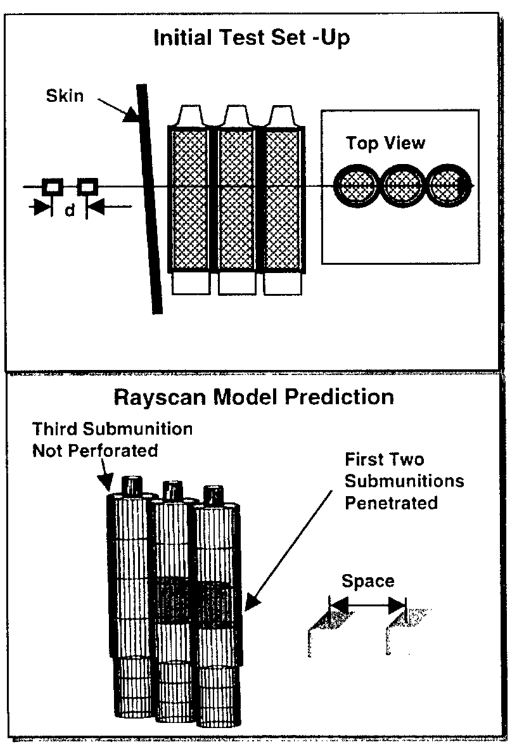


Figure 23. RAYSCAN Predicts Enhanced Penetration from Follower Fragment Test

New logic is required to compute the damage from projectiles that impact at or near the same time. These impacts occur within the time it takes a fragment to penetrate a plate and the hole diameter to fully grow. This time is usually on the order of 10 to 20 μs. Fragments that impact within this time are modeled as true multiple impacts. Since these two fragments are impacting the target at the same time there is an increase in overall penetration as a function of fragment spacing. This spacing is the overall distance between fragment impacts. Obviously, as the spacing increases there is less shock interactions between fragments. There is also a distance were both fragments only penetrate as individual fragments. At this spacing there are no shock interactions that would enhance the overall penetration.

There is an interaction between shock waves which are created by each fragment impact. Each fragment creates a pressure wave that interacts with its neighboring fragment shock. The intensity of the shock is a function of the spacing between the projectile (d). This interacting shock front can combine to form a mach interaction, which can spall the backside of the plate. The current penetration model has been upgraded to account for this enhanced penetration from multiple spaced fragment impacts. The increase in penetration is computed as a function of separation distance d. This increase is added to the fragments overall penetration giving higher residual masses and velocities. The SPHINX hydrocode was run to examine the damage from closely spaced projectiles. An illustration of the hydrocode run with two 50 gm cubes impacting a submunition at 0 deg obliquity is shown in Figure 24.

These fragments are spaced at several different distances to allow for the difference in overall damage. The hydrocode demonstrated that the damage from their closely spaced fragments was higher compared to the farther spaced impacts. A velocity plot is shown at 60 μs where the closely spaced impacts have loaded the rear wall of the submunition with more overall velocity compared to the spaced impacts. This change in velocity is directly related to spacing. The overall mass of the fragments seemed to hold together better at smaller distances d, which supports the analytical calculations of larger residual masses.

The same calculation was performed at an impact obliquity angle of 70.0 deg. These closely spaced fragments imparted more overall damage compared to the spaced fragments. This enhanced damage is partly due to the first fragment impacting its neighboring fragment. After they impact, the first fragment impacts

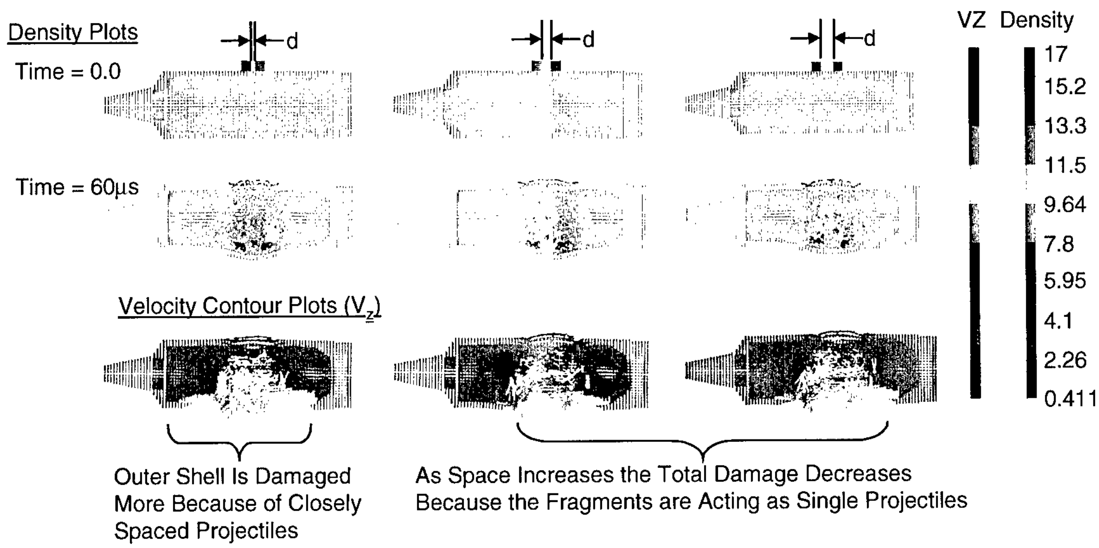


Figure 24. Multiple Impact of 50 gm Cubes Normal to Submunition Canister

the second and deflects to penetrate the opposite side of the submunition. The second fragment continues and penetrates the back plate of the submunition. This same effect is seen as the spacing d is slightly increased. The bulge on the aft side of the submunition is smaller compared to the tightly spaced impact. The last run shifted the fragment to 1.25 d where there was no damage to the aft wall. However, there appears to be enhanced damage to the outer shell. This damage is caused because there is minimal shock interactions and the fragments skip more due to lower overall failure stresses in the outer shell. These calculations are shown in Figure 25.

When those fragments impact close together or with small time differentials, there is some increase in penetration due to the combined energies or pressure of both fragments impacting close together. This combined effect does not occur when fragments are spaced far apart. A new penetration damage model is currently being incorporated into RAYSCAN, which uses current penetration equations with additional logic that accounts for closely spaced and timed impacting fragments. Near miss warhead technology at small miss distances generates extremely high spray densities making this model essential when computing accurate target submunition damage. The fragment length is L while "d" is the distance between each rod at impact. If d>>L then each rod is treated as a single penetrator. The loading on the submunition wall is modeled as two different impacts. However, there exists a d/L ratio that caused neighboring fragments to induce enhanced impact pressure, increasing overall penetration potential. our model computes all rod points and determines rod neighbor as a function of d/L. The difference in impact time is also computed. At this time, the first rod penetrates through the weakened wall of the target. The target material is nearly perforated or detached from the cylindrical wall giving the second fragment lower resistance during penetration.

A theoretical probability equation can be used to determine the total number of multiple impact occurrences that may exist. The probability that a fragment will impact near another is predicted by

$$P_o = \frac{e^{-\zeta}\,\zeta^k}{k!} \tag{9}$$

where P_o is the probability of exactly k impacts per crater, ζ equals the number of impacts multiplied by the impact crater area divided by the total rod cloud area.

So, let

$$\zeta = \frac{NA_C}{A_T} \tag{10}$$

and if the crater radius is 1 in. and the deployed cloud radius is 12 in. then given 300 fragments the probability of two fragments impacting with a fragment crater is 27 percent. The probability that three fragments impact with a crater is 18 percent.

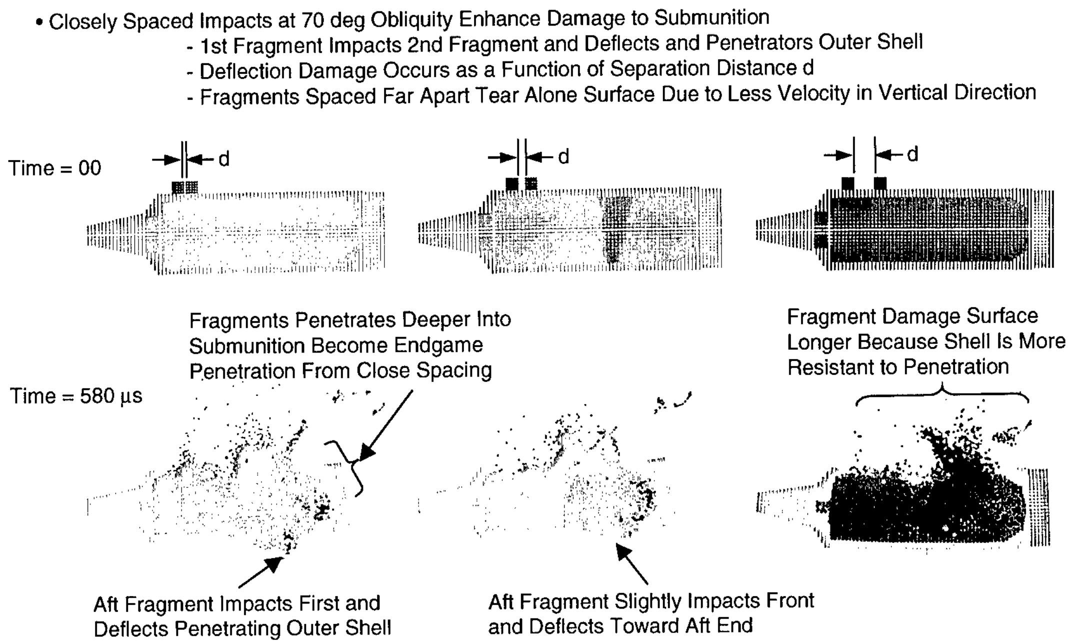


Figure 25. Multiple Fragment Impacts at High Obliquity

These simple penetration tests into submunitions demonstrated that the current models could predict enhanced damage from temporal spaced projectiles. A full target payload test was performed that fired 225 tungsten cubes into a submunition payload. A 2.5 ton Mat-projector gun was placed behind a blast shield to choke the blast products and allow all damage from the fragments. The payload was placed inside a soft recovery house at a 20 deg strike angle within represent actual endgame conditions. The payload was hit with approximately 150 fragments traveling at 2 km/s. An illustration of the initial test setup is shown in Figure 26.

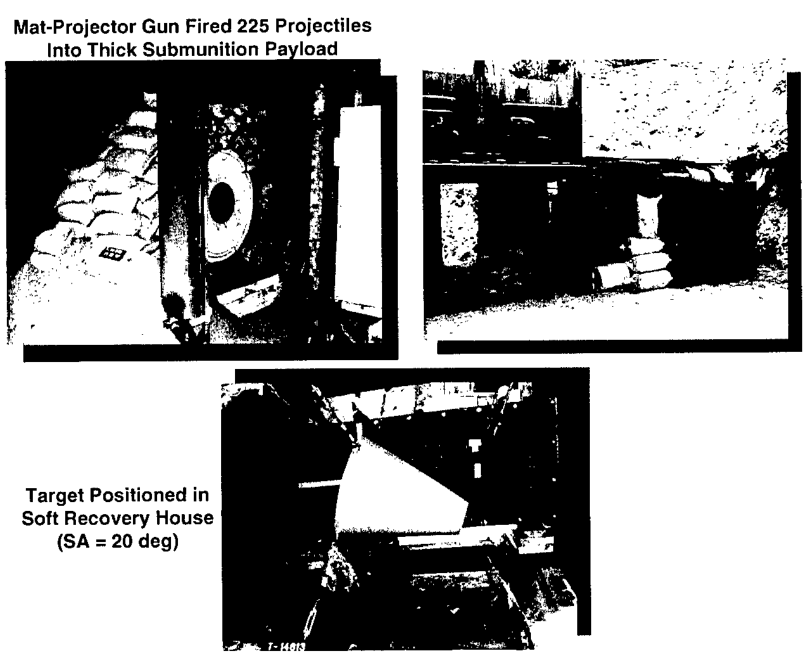


Figure 26. Setup Configuration of Test against Submunition Payload

This final test configuration shows the gun position relative to the target payload. Six tons of sandbags were placed around the gun to increase overall gas confinement. This added confinement is believed to have enhanced total ejection velocity while the soft recovery structure built about the target confined all the debris. Concrete and steel weights were placed on top of the test roof. This mass restricted the amount of debris leaving the test range. Figure 27 is a view of the test site after explosive detonation.

The test demonstrated a dense cloud of tungsten fragments is highly lethal against a thick wall submunition payload. The target was reconstructed showing most of the submunitions were totally blown apart or ruptured with single or multiple holes. The RAYSCAN model was employed and demonstrated test lethality with an accuracy of 5 percent. This calculation demonstrated that the approach taken to compute multiple impacts is promising and logical. It is believed that small elements with new penetration logic can improve future calculation accuracy. An illustration of the RAYSCAN prediction with the damaged test target is shown in Figure 28.

Further lethality studies were performed to investigate the new multiple impact model against a representative submunition payload. Also, deformable and blast fragmentation warheads were compared to rod warhead technology. The analysis focused on one encounter where the missile flew 1 m above the TBM target. The warhead lethality was plotted as percent of submunitions perforated versus total rod warhead weight as a function of single rod mass. All the analysis considered tungsten rods with an L/D of 4. The results of this analysis is shown in Figure 29.

The performance of the deformable and blast fragmentation warheads were far less when compared to the KE-rod warhead. This is because KE-rod warheads deploy 8 to 30 times more mass toward the target. Also, fragmenting warheads usually have low mass fragments while KE-rod warheads contain heavy metal penetrators.

The curves show that light rods outperform heavier rods when small warhead weights are used. As the total warhead weight is increased, all weights began to converge. The 6.25 gm rods deploy eight times more rods compared to 50 gm rods. This generates eight times more shotlines per rod giving higher probability of hitting a submunition. The strike angle is 20 deg, which generates 70 deg obliquity angles. However, at these low strike angles the collar on the submunition is flat which has an obliquity of 20 deg. The warhead deploys thousands of these small rods penetrating all the collars on each visible submunition. The rods that impact on the cylindrical shaft only penetrate if the rod is aligned less the 30 deg at 70 deg obliquity.

This model does not account for ricochet effects, which would occur. These light rods would travel to the next submunition tier impacting their collar or fuse component.

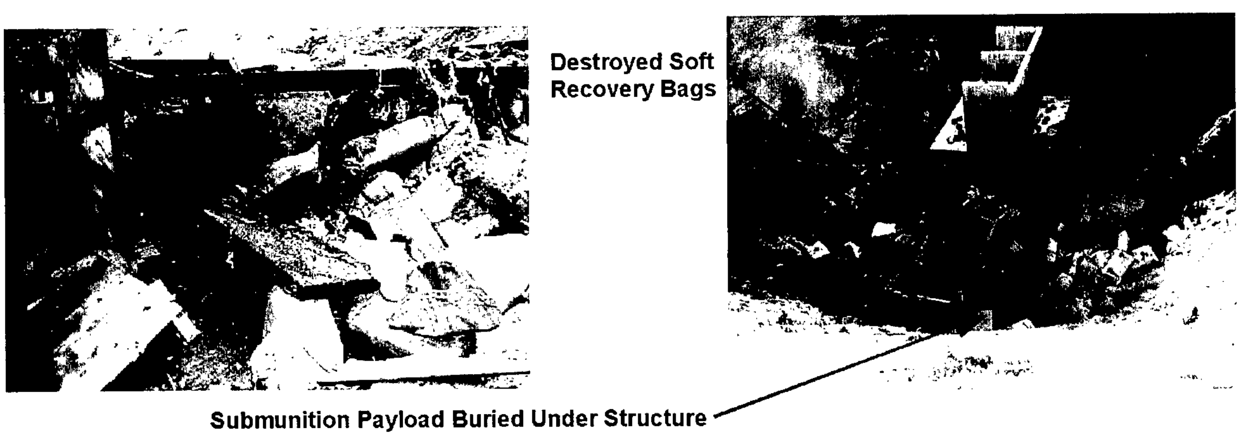


Figure 27. View of Test Site after Warhead Detonation

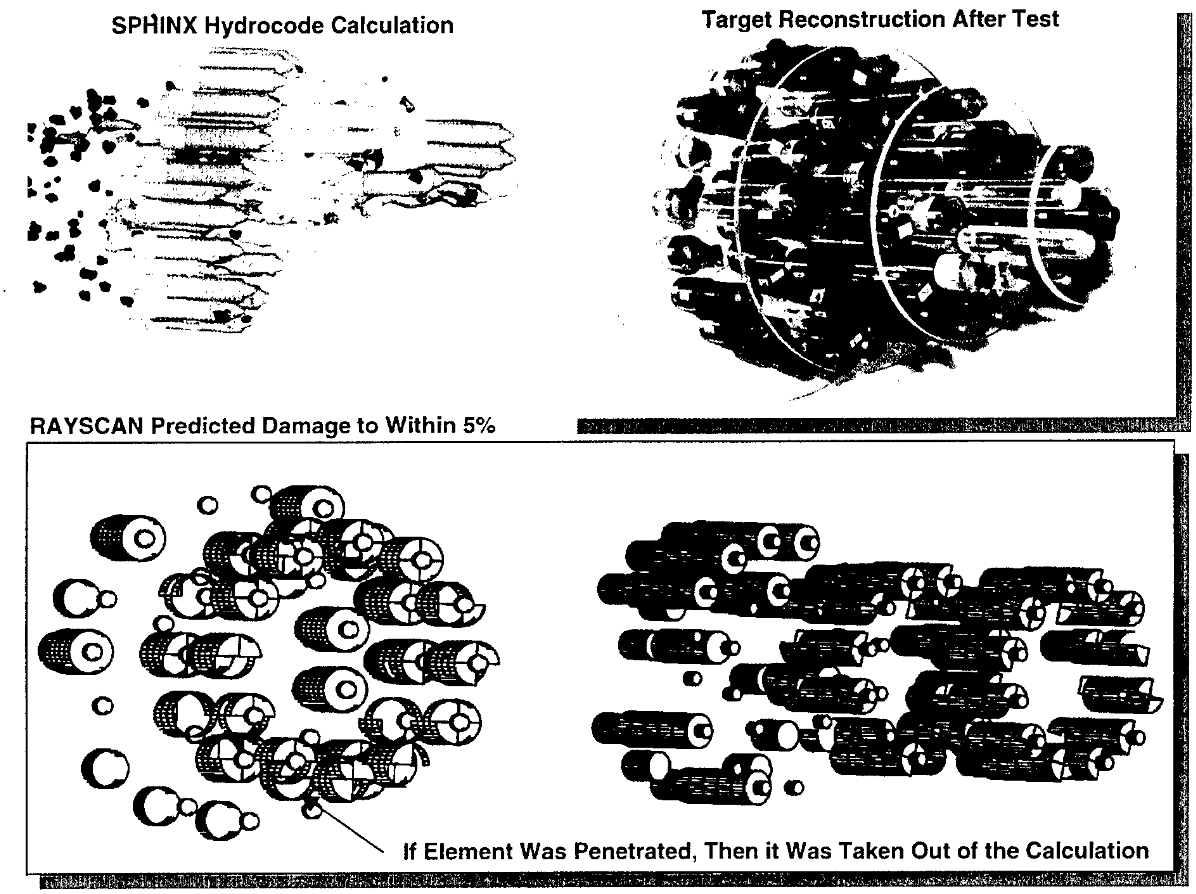


Figure 28. Damage Comparison Between RAYSCAN and Mat-projector Test

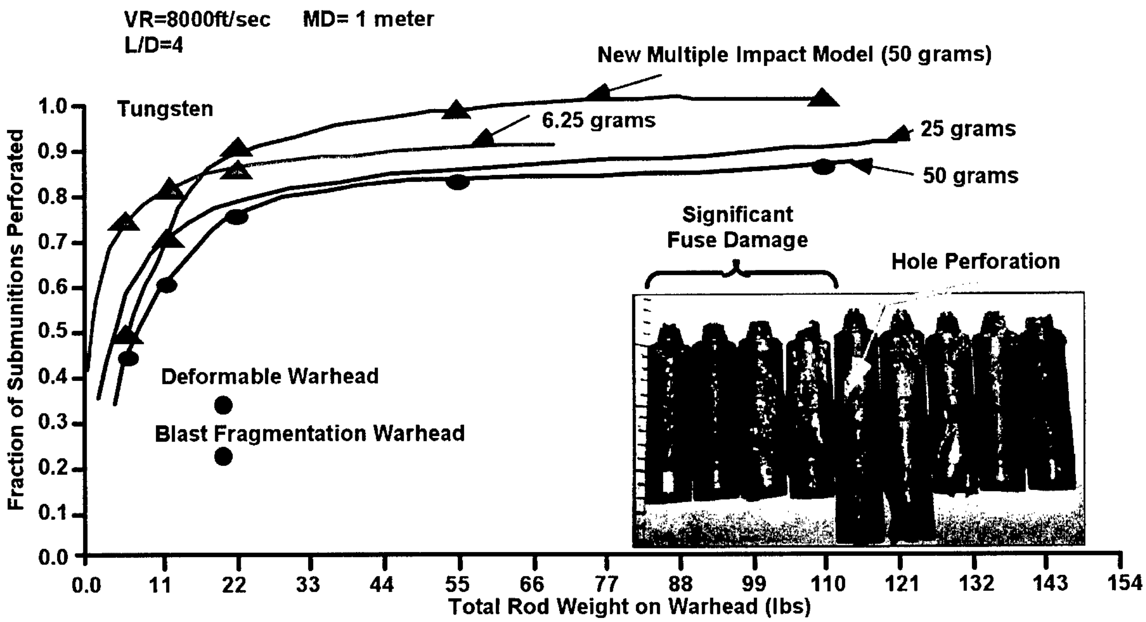


Figure 29. KE-rod Lethality with New Multiple Impact Model

Our test program showed significant damage to fuses on the third tier. It appears that a flux of projectiles that break or skip travel through the payload at high velocity are capable of penetrating the fronts of submunitions.

The new rod follower model was used to investigate the difference in lethality using a 50 gm rod. The curve shows that rods that are spaced close do enhance the overall lethality of the weapon. This model shows a significant increase in overall lethality. It is clear that current single raytrace techniques are conservative and do not account for closely speed impacts. Current studies are underway to validate this new damage models to test and hydrocode data.

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